

# ***AN OVERVIEW OF THE NASA AEROSPACE FLIGHT BATTERY SYSTEMS PROGRAM***

***2002 NASA AEROSPACE BATTERY WORKSHOP***

***HUNTSVILLE, ALABAMA***

***November 17-19, 2002***

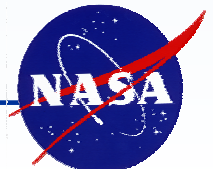
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# NASA AEROSPACE FLIGHT BATTERY SYSTEMS PROGRAM

**Unified NASA-wide program, managed by GRC, addressing battery related issues. Program goal is to ensure the availability of qualified flight hardware to support NASA's aerospace battery requirements.**

## Program Objectives

- Provide NASA with validation guidelines and the supporting database for technology selection of hardware and processes relating to aerospace batteries
- Develop, maintain and provide tools for the validation and assessment of aerospace battery technologies
- Disseminate validation and assessment tools, quality assurance reliability and availability information to the NASA and aerospace battery communities
- Accelerate the readiness of technology advances and provide infusion paths for emerging technologies

## Major Players

NASA centers - GRC, GSFC, MSFC, JSC, JPL, LaRC, KSC, AFRL, Navy, CIA, The Aerospace Corporation

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## Approach

NASA-wide program, with tasks distributed among various centers, run in close coordination with other government agencies

Address battery systems level issues as well as primary and secondary cell/battery technology issues

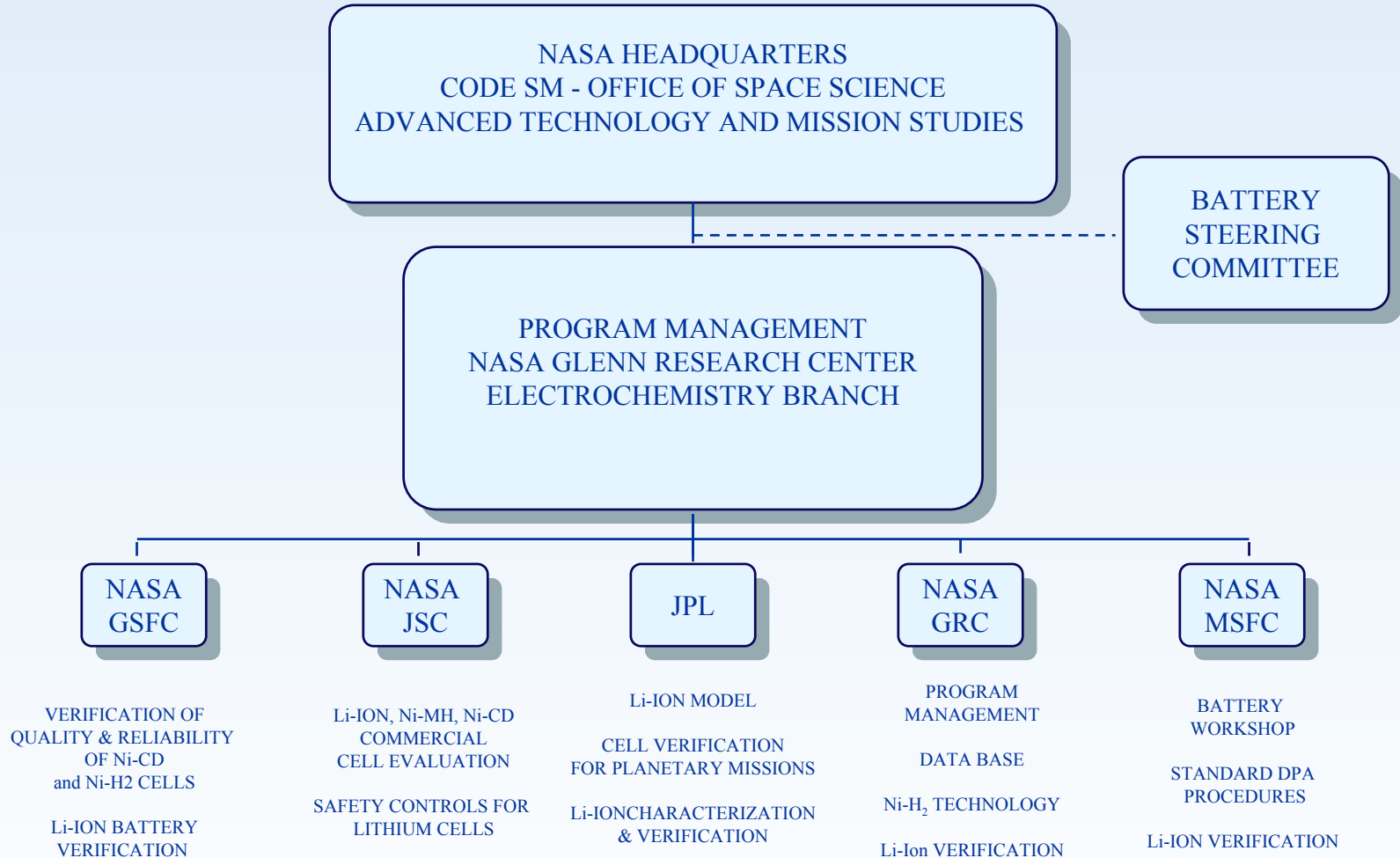
- Maintain current battery technology
- Increase fundamental understanding of primary and secondary cells and batteries
- Establish specifications, design and operational guidelines
- Open and maintain communication lines within NASA and the aerospace community

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# NASA AEROSPACE FLIGHT BATTERY SYSTEMS PROGRAM

## PROGRAM TASK RESPONSIBILITIES



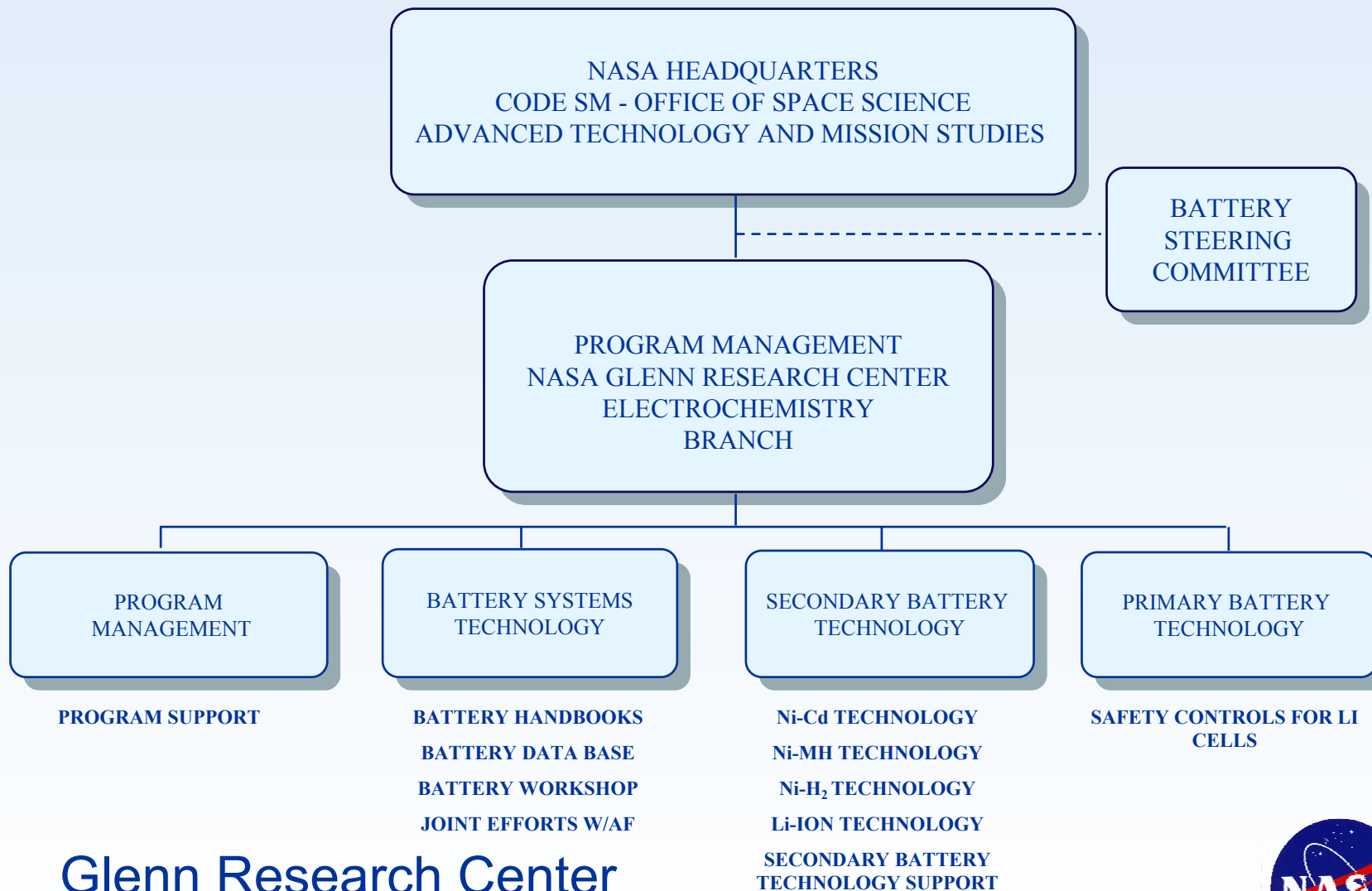
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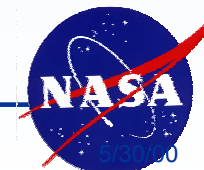
# NASA AEROSPACE FLIGHT BATTERY SYSTEMS PROGRAM

## PROGRAM ORGANIZATION



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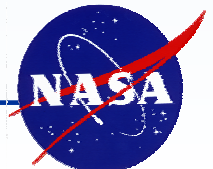
# BATTERY SYSTEMS TECHNOLOGY TASK

## OBJECTIVES:

- To improve reliability of energy storage space power system design, integration, and checkout
- Address systems aspects - integration of cells into batteries and batteries into power systems

## TASKS:

- NASA Battery Handbooks
- Battery Data Base
- NASA Battery Workshop
- Joint Efforts With The Air Force
- Flight Battery Operations Telecon



# NASA BATTERY HANDBOOKS

## OBJECTIVE:

- Define good consistent practices for the design, integration and checkout, and testing of primary and secondary battery systems.
- Provide background information, guidelines and requirements related to battery systems to aid in ensuring mission success

## Approach:

- Develop documents that serve as guidelines and checklist for the procurement of cells for flight projects
- Aid in development of specifications for procurement
- Provide rationale for selection of design features for specific applications
- Define representative values and ranges for technical specifications for critical design parameters

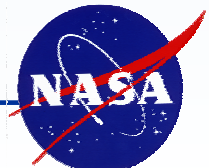
*Documents produced via combination of internal and contracted efforts - Contracts with the Aerospace Corporation, various industry consultants*

## Publications:

- NASA Specification for Manufacturing and Performance Requirements of NASA Standard Nickel-Cadmium Cells – NHB 8073.1, 1988
- NASA Handbook for Nickel-Hydrogen Batteries – NASA RP 1314, 1993
- Handbook for Handling and Storage of Nickel-Cadmium Batteries – Lessons Learned – NASA RP 1326, 1994
- Primary Battery Design and Safety Guidelines Handbook – NASA RP 1353, 1994
- Review and Status of Lithium-Ion Cell Technology for Aerospace Applications – JPL Internal Document D-13332, 1997
- Guidelines for the Procurement of Aerospace Nickel-Cadmium Cells – JPL Publication 97-6, 1997
- An Overview of the Design Development and Application of Nickel-Hydrogen Cells – NASA TP TBD, 2002
- Guidelines Document for Silver-Zinc Cells – NASA TP TBD, 2003

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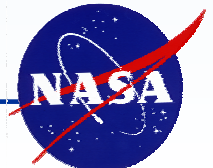
# ***BATTERY DATA BASE***

## **OBJECTIVE:**

- **Develop data base for the dissemination of test data related to the validation of battery technologies for aerospace applications**

## **APPROACH/STATUS:**

- **Majority of Program sponsored testing is at Crane**
- **Developed web-based system for access of operational cycle test data**
  - **Crane test data post 1990**
  - **Data from Lockheed Martin Nickel-Hydrogen Test Program**
  - **Tests sponsored at other installations being incorporated**
- **Data is available on-line to test sponsors**
  - **Real-time, processed and archived test results**
  - **Limited access can be granted as needed via approval from test sponsor**



# ***NASA BATTERY WORKSHOP***

## **OBJECTIVE:**

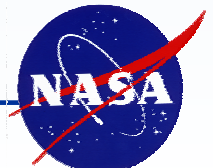
- **Provide forum for open communication of battery related activities**
- **Address technology status of established and emerging technologies**

## **APPROACH/STATUS:**

- **Sponsor annual workshop**
  - **Started in 1968 – Goddard Battery Workshop**
  - **1985 – Sponsorship assumed by Battery Program**
  - **Moved to MSFC in 1990**
- **Topics Covered**
  - **Research and development work on state-of-the-art aerospace battery technologies**
  - **Flight and ground test data**
  - **On-orbit operation and problem resolution efforts**
  - **Focused topic to address current issues relating to aerospace batteries**

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# ***COOPERATIVE EFFORTS WITH THE AIR FORCE***

## **OBJECTIVE:**

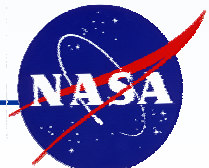
- Leverage efforts by combining resources with the Air Force for efforts supporting the verification of secondary cells/batteries for aerospace applications.

## **APPROACH/STATUS:**

- **Memorandum of Understanding**
  - Initiated in 1996, renewed in 1999
  - Formal arrangement expired earlier this year
  - Efforts continue
- **Areas of common interest**
  - Common pressure vessel (CPV) nickel-hydrogen batteries
  - Single pressure vessel (SPV) nickel-hydrogen batteries
  - Individual pressure vessel (IPV) nickel hydrogen cells
  - Super nickel-cadmium cells
  - Lithium Ion Verification Testing

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# ***FLIGHT BATTERY OPERATIONS TELECON***

## **OBJECTIVE:**

- Provide a forum for communications among users of aerospace battery technologies to share experiences related to flight battery integration, management and operations, specifically nickel- hydrogen for the present and lithium ion technology for future missions.

## **APPROACH/STATUS:**

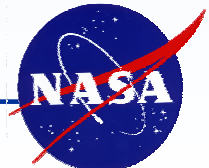
- Convene monthly telecons on relevant topics related to flight batteries

### **RECENT TELECON PRESENTERS/TOPICS**

- Fred Cohen and Penni Dalton, “Status of Nickel Hydrogen Batteries on Space Station”
- Tom Miller – “An Update on Design Features and Testing Status of Ni-H<sub>2</sub> Cells/Batteries”
- Ray Zercher, “Status of CPV Ni-H<sub>2</sub> Batteries on MGS, Genesis, Mars Orbiter-05, Odyssey, and Stardust”
- Jon Armentrout – “HST Reliability Studies”
- Anisa Ahmad – “Status of GSFC Programs – MAP, Landsat, TERRA”
- George Methlie, “Lithium-Ion as a Replacement for Nickel Hydrogen – Progress/Status”
- Rob Chambers – “Nickel-Hydrogen – Oddey Mission”
- Dan Debacari – “Nickel-Hydrogen Handling and Safety Considerations”
- Albert Zimmerman – “Nickel Hydrogen Battery Performance Signatures”
- Gopal Rao, Harry Wajsgas, Stanley Krol – “On-orbit Health Check of HST Nickel-Hydrogen Batteries”

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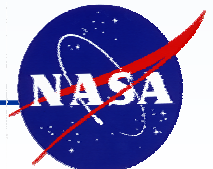
# SECONDARY BATTERY TECHNOLOGY

## OBJECTIVE:

- Improve performance, quality, safety and reliability of secondary battery systems.
- Maintain and improve established technologies and aid in development of emerging technologies

## TASKS:

- Nickel-Cadmium Battery Technology
- Nickel-Hydrogen Battery Technology
- Nickel-Metal Hydride Battery Technology
- Lithium-ion Battery Technology
- Secondary Battery Technology Support



# ***NICKEL-CADMIUM BATTERY TECHNOLOGY***

## ***VERIFICATION OF SECONDARY Ni-Cd CELLS***

### **OBJECTIVE:**

- Provide independent verification of manufacturing flight cells by procuring and testing representative cells from various manufacturers

### **APPROACH /STATUS:**

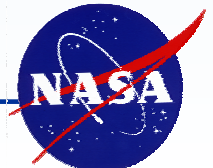
- Current efforts focus on monitoring performance of cells representative of flight lots for ongoing and upcoming NASA missions.

### **COMPLETED EFFORTS:**

- Over 200 cells tested – various temperatures, DOD
  - Evaluations of NASA Standard cells from representative flight lots
  - Advanced Ni-Cd cell designs
  - Verification testing of potential replacements for NASA Standard Ni-Cd
    - Saft, Sanyo, EP Super Ni-Cd, EP Magnum Ni-Cd, Acme
  - Cell verification testing of cells with various storage histories

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# ***NICKEL-HYDROGEN BATTERY TECHNOLOGY***

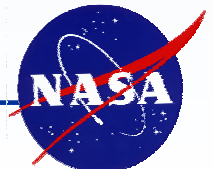
## ***IPV CELL VERIFICATION***

### **OBJECTIVE:**

- Provide independent verification of design and component variations to manufacturing flight cells. Evaluate effects of storage conditions on performance and life.

### **APPROACH/STATUS:**

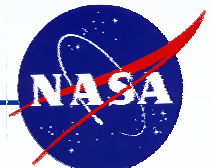
- Over 200 cells have been tested
- Evaluate effects of advanced design features in flight hardware
- Tests run at various DOD and Temperatures
- Evaluate charge control methods



# ***NICKEL-HYDROGEN BATTERY TECHNOLOGY***

## ***IPV CELL VERIFICATION***

- **Verification of 26% KOH**
  - Cells From Hughes, Eagle Picher, Gates, Yardney
  - Cells of ISS Design
- **Advanced design features**
  - Catalyzed wall wick
  - Cell stacking – Back to back vs Recirculating
  - 350AH, 5 ½” Hughes GEO Cell Evaluation
- **Evaluation of cell components**
  - Nickel electrode impregnation process – alcoholic and aqueous
  - Separator – Asbestos and Zircar
  - Passivation of electrode plaque
- **Storage Test**
  - Dry Storage
  - Wet storage



# **NICKEL-HYDROGEN BATTERY TECHNOLOGY**

## ***CPV Battery Evaluation***

### **OBJECTIVE:**

- Evaluate potential of CPV technology to meet NASA's needs. Develop data base to insure optimum battery management and support for missions
- **Evaluation Of 2.5" CPV Batteries**
  - 10, 2 Cell, 10AH CPV Batteries - Eagle Picher
  - LEO life test - 40% DOD, 10°C
- **Characterization Of 2.5" CPV Batteries**
  - Characterization/Mission Simulation Tests On 2.5"CPVTests
- **Joint Task With Air Force - 3.5" CPV Batteries**
  - 21, 2-cell, 45AH CPV Batteries - Eagle Picher
  - 3 PACKS - 2 LEO 40% DOD -5°C, 10°C, 1 GEO
- **Evaluate CPV Ni/H<sub>2</sub> battery technology designs –**
  - 2.5 and 3.5" Diameter Cells
    - Improved stack designs
    - 26% and 31% Electrolyte concentration
    - Wall wick variations

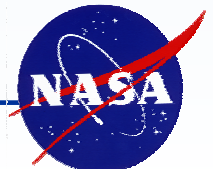


# ***NICKEL-HYDROGEN BATTERY TECHNOLOGY***

## ***SPV BATTERY EVALUATION***

### **OBJECTIVE:**

- Evaluate potential of SPV technology to meet NASA's future needs
- **JOHNSON CONTROLS - SPV BATTERY**
  - 28 VOLT, 50 AH BATTERY
  - 35% DOD, 10°C ~44,000 CYCLES





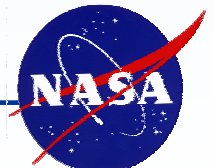
# ***NICKEL-METAL HYDRIDE TECHNOLOGY***

## **OBJECTIVE:**

- Evaluate potential of Ni-MH technology to meet NASA's future needs

## **APPROACH/STATUS:**

- Current efforts focus on evaluation of COTS products for EVA'S, IVA'S for space station
- Performance and abuse evaluation of cells from various vendors to determine best available commercial Ni-MH
- Develop and certify Ni-MH battery for EMU backpack, advanced helmet lights, cuff check list
- Completed evaluation of aerospace design cells—
  - Eagle Picher
  - Sanyo
  - Ovonics



# ***LITHIUM -ION BATTERY TECHNOLOGY***

## ***Li-ion Technology Assessment***

### **Objective:**

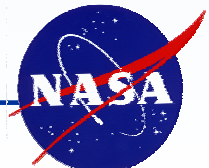
- Evaluate potential of Li-Ion technology to meet NASA's future needs. Enable technology development for aerospace applications
- Develop performance database and user guidelines of the lithium ion battery technology.

### **Approach/Status:**

- Technology review - status assessed for aerospace applications
- Characterize and define performance envelopes of prototype cells as related to NASA's planetary missions.
  - NASA/DoD Inter-agency Program
  - Cells developed for specific NASA missions, such as Mars Lander (MSP01) and Mars Rover (Mars Athena Rover and Mars Exploration Rover).
  - Cells from other sources
- Extensive database generated –
  - Rate characterization as function of charge/discharge rate and temperature
  - Cycle life at various temperatures and various depths of discharge
  - Coulombic and energy efficiencies at various temperatures
  - Heat evolution rates at different rates of charge and discharge
  - Performance in a multi-cell environment
- Address planetary mission requirements
  - Radiation tolerance / Stand time during cruise

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# LITHIUM -ION BATTERY TECHNOLOGY

## *LITHIUM ION CELL/BATTERY CHARACTERIZATION*

### **Objective:**

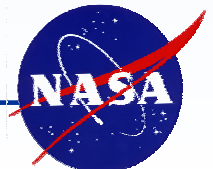
- To qualify the best lithium-ion “space” batteries in environments that mimic as closely as possible those the batteries will experience if used in the future LEO and GEO missions

### **Approach/Status:**

- Using the most advanced cells available, prepare battery packs that will approximate the batteries that would be used for LEO/GEO missions
- Conduct various tests over a broad range of operating temperatures (hot and cold cases, along with a nominal case), coupled with a first-cut mission profile that includes launch.
- Evaluate different charge schemes – determine optimal charge control
  - Parallel string charging
  - Cell-level monitoring only to determine end of charge
  - “Smart” battery
- Batteries from AEA Technologies and Saft

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# LITHIUM -ION BATTERY TECHNOLOGY

## *Li-Ion LEO/GEO Verification Test Program*

### **Objective:**

- Assess the current and developing capabilities of Li-Ion technology for LEO and GEO applications
- Develop the database that will aid in the qualification of Li-Ion for NASA's LEO and GEO missions

### **Approach/Status:**

- Work with statistician to develop DOE to address program test goals and resource limitations
- Identify flexible matrix that will maximize use of available resources and incorporate 'incremental funding' and multiple partners in test program
- Completed initial cell purchases

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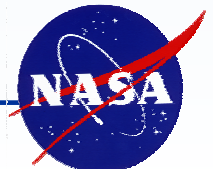
# LITHIUM -ION BATTERY TECHNOLOGY

## *Li-Ion LEO/GEO Verification Test Program*

### Cell Specifics

- 50 Aerospace quality cells from each of three vendors:
  - Eagle-Picher Technologies      Model #SLC-16002
  - Saft America      Model # G4
  - Lithion      Model # INCP 95/28/154

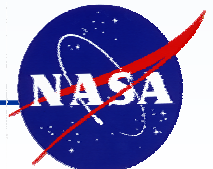
Testing to take place at Crane, MSFC, GRC



# LITHIUM -ION BATTERY TECHNOLOGY

## *Li-Ion LEO/GEO Verification Test Program*

- **Focus on LEO with initial cell purchase**
- **Acceptance/Characterization Tests recently completed at Crane**
- **Final LEO Test conditions are being established**
- **Test Variables**
  - Vendor
  - Depth of Discharge – 3 levels
  - Test Temperature – 3 levels
  - Charge Control – 3 voltage limits
- **Additional test articles to be procured in FY03**



# ***LITHIUM -ION BATTERY TECHNOLOGY***

## ***Li-Ion Commercial Cell Evaluation***

### **Objective:**

- **Develop an understanding of the safety issues relating to space use and qualification of new Li-Ion technology for manned applications.**
- **Enable use of new technology batteries into GFE equipment - laptop computers, camcorders**
- **Establish a data base for an optimized set of cells (and batteries) exhibiting acceptable performance and abuse characteristics for utilization as building blocks for numerous applications.**

### **Approach/Status:**

- **Perform Evaluation – Performance and thermal characterization, evaluated abuse tolerance**
- **Typical manufacturers include Energizer, Maxell, Blue Star, Sony, Sanyo, Toshiba, Panasonic, Ultralife, and YTP**
- **Battery components such as cell voltage protection circuits, charger controls (chips), fuel gauges, miscellaneous IEEE electronic components, and commercial chargers for specific commercial equipment have been evaluated for use in flight equipment.**
- **Li-Ion batteries certified for use in Canon Camcorder, IBM Thinkpad, and a dosimeter**
- **Camcorder charger has been safety certified for flight**
- **Multiple applications are considering adaptors to allow use of the flight approved designs**

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# ***SECONDARY BATTERY TECHNOLOGY SUPPORT***

## ***Development of DPA Test Procedures***

### **OBJECTIVE:**

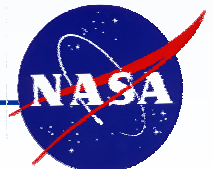
Define general guidelines to be followed by facilities performing DPA procedures to minimize the discrepancies that exist with DPA testing results from different facilities by defining a uniform set of guidelines by which DPA's can be conducted.

### **APPROACH/STATUS:**

- Define guidelines that will promote stability and consistency in DPA results.
- Incorporate into an expert system software tool that can be utilized to aid in troubleshooting specific cell failures and offer suggestions as to what testing might be most appropriate on the failed cell.
  - Aerospace developed Expert Systems Approach
  - Define cell/component physical characteristics new and at failure along with signature performance – Expert System leads you to probable cause for failure
- Ni-H<sub>2</sub> Complete and available for distribution
- Ag-Zn in Process
- Li-Ion Planned

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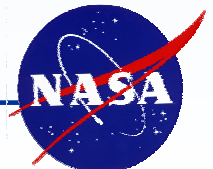
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# ***SECONDARY BATTERY TECHNOLOGY SUPPORT***

- **Battery Models**
  - Ni-Cd
  - Ni-H<sub>2</sub>
  - Li-Ion – support efforts with NRO
- **Radiation Tolerance Testing**
  - Evaluate suitability of aerospace design cells for deep space missions
    - Li-Ion
    - Super Ni-Cd Cells



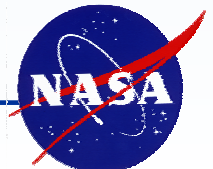
# ***PRIMARY BATTERY TECHNOLOGY***

## **OBJECTIVE:**

- Improve performance, quality, safety and reliability of Li primary battery systems

## **PRIMARY BATTERY TECHNOLOGY TASK:**

- Safety controls for lithium cells



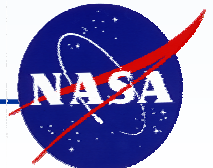
# ***SAFETY CONTROLS FOR LITHIUM CELLS***

## **OBJECTIVE:**

- Increase short circuit hazard tolerance of Li primary cells - internal cell short could result in a catastrophic failure

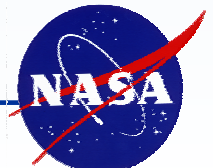
## **APPROACH/STATUS:**

- Address LiBCX C, D and DD cell designs
- Reduced molarity of electrolyte - reduce capability to sustain high short circuit current for extended time
  - Determine minimum concentration to maintain capacity requirements
  - Reducing short circuit current to prevent venting or rupture
- Performance, abuse, shelf life determinations performed for qualification of cells with reduced electrolyte levels
- Levels established for C and D – unable to certify improved DD cell
- Investigate hazard controls for other Li cell chemistries (Li-CF, Li-SOCl<sub>2</sub>, Li-MnO<sub>2</sub>, Li-FeS<sub>2</sub>)
  - Shut-down separator of the Eagle-Picher Li-CF
  - Low molarity Li-SOCl<sub>2</sub> cells
- Evaluation of Li-FeS<sub>2</sub> AA commercial cells as replacement for alkaline AA cells
  - Better voltage control, more capacity at higher rates, lower temperature operation



# ***SUMMARY REMARKS***

- **NASA-wide, coordinated program**
  - Promotes communication and cooperation between NASA Centers
  - Covers Battery Systems, Primary and Secondary Batteries
  - Mechanism for addressing battery and cell related issues as they arise
- **Well integrated program complements battery related developments funded elsewhere in the agency**
  - Battery Program integrated with mission and technology development programs
  - Provides verification of technology developments funded by other programs
  - Provides tools to aid in determining reliability of aerospace batteries and to aid in performance predictions for NASA missions
- **Direct Benefits to NASA Missions**
  - Battery test bed, test programs contributed to the development of operational strategies for batteries on missions such as UARS, GRO, EUVE, TOPEX
  - Developed database and validated technology that has been selected for numerous NASA missions
  - Developed safe batteries for manned applications



# **NASA AEROSPACE FLIGHT BATTERY SYSTEMS PROGRAM**

## **Program Participants**

- **Jeff Brewer – MSFC**
- **Bobby Bragg - JSC**
- **Ratnakumar Bugga – JPL**
- **Barbara McKissock – GRC**
- **Gopal Rao – GSFC**
  
- **Additional support from other individuals at  
respective centers**

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